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Upper Devonian “griottes” facies of the Ben-Zireg area (Bechar basin, southwestern Algeria): stratigraphy, microfacies analysis and paleo-environmental reconstruction

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Abstract

The widespread ‘griotte’ facies of the Late Devonian (Frasnian to Famennian) in the Ben-Zireg area of the Bechar basin (Southwestern Algeria) is described here from three sections (BZI, BZII and BZIII) which have been sampled bed-by-bed from the ‘Griotte’ limestone of the Ben-Zireg Formation. Based on macro- and microfacies analysis, this formation has been divided into three members: the Lower Member consists of ‘griotte’ limestone, the Median Member consists of clayey-limestone ‘griotte’, and (iii) the Upper Member consists of shales with intercalations of ‘griotte’ limestone. The ammonoid specimens recollected in this formation allow to characterize three Late Devonian biozones: the *Cheiloceras* Zone (UD II) of the Early Famennian, the *Goniclymenia* (UD V) and the *Kalloclymenia* (UD VI) zones of the Late Famennian. Based on the field observations and the analysis of 270 thin sections, six microfacies types (MFT-1 to MFT-6) have been identified. They are dominated by biomicritic wackestones and mudstones characterizing a quiet marine environment corresponding to a distal ramp with deposits containing tempestites echoes and internalites fine grained supplies.

Keywords: Griotte limestone facies, Ben-Zireg Formation, Bioclastic content, Paleoenvironment, Late Devonian, Bechar Basin, Southwestern Algeria.

1. Introduction

The Upper Devonian strata of the Ben-Zireg area (Bechar Basin, southwestern Algeria) is represented by the ‘griotte’ type facies (Strakhov, 1958; Tucker, 1975), discovered first by Flamand (1911) then described by Massa et al., (1965). This particular facies is known as nodular cephalopod limestones often rich in ammonoids and is characterized by its reddish color. This facies was developed during the Devonian of the Gondwana margins and qualified goniatico-rosso. Similar facies was developed during the Jurassic in the Tethys and Peri-Tethys areas, and qualified as ammonitico-rosso facies (Auboin, 1964; Bourrouilh, 1981; Elmi, 1981a, b; Elmi and Aneur, 1984; Cecca et al., 1992). The palinspatic profile of their deposition corresponds to paleohighs as basement rise, drowned shallow platform and volcanic rises (Lubeseder et al., 2010) which controlled the lateral variations of the facies, the differential condensation and the rate of nodularizations and clay intercalations. ‘Griotte’ facies has been described in several regions throughout the world : in the Saoura Valley of Algeria (Menchikoff, 1932; Benhamou et al., 2004; Mahboubi et al., 2015), the Anti-Atlas of Morocco (Wendt et al., 1984; Wendt, 1988; Lubeseder et al., 2010), the Pyrenees of Spain where this facies is dated of Devono-Carboniferous transition (Mirouse, 1992; Mey, 1967; Sanz-Lopez, 2002; Garcia-Lopez and Sanz-Lopez, 2002) and consist of limestones with

matrices and cavities containing hematitic bioconstructions (Mamet and Pr at, 2003; Garc a-L pez and Bastida, 2002), in the Montagne Noire of France 'Griotte' facies is represented by reddish nodular limestone levels attributed to the Frasnian and Famennian (Maurel, 1966; House et al., 1985; Becker and House, 1994; Mamet and Perret, 1995; House et al., 2000), and in the Rhenish Mountains of Germany where is represented by pelagic limestones containing ferromagnesian nodules (Becker, 1988; Walliser et al., 1988, 1989; Dreesen et al., 1988; Korn, 2002; Tucker and Wright, 2009; Heuer et al., 2015). In Austria griotte facies is intercalated within limestones series of Devonian in age (B hm, 1992; B hm et al., 1999). This facies has also been reported in Asia, particularly in Vietnam (Komatsu et al., 2014, K nigshof et al., 2017) and China (Chen et al., 2001; Chen et al., 2002; Chen and Tucker, 2003).

In Algeria, griotte facies is particularly well developed in the northwestern margin of the Saharan domain (Fig. 1A). In the Saoura Valley (SW Algeria), this facies forms the uppermost part of the Cheffar El Ahmar Formation in Frasnian Ib and the Marhouma Clay Formation in the Famennian (Zones III, IV, V).

This facies also outcrops in the western part of the Bechar Basin (regions of Soltane El Betom, Maider El Mahadjib and Theniet Haidoura, North side of Djebel Antar and Djebel Horreit) within a condensed series forming a decametric limestone ledge (Menchikoff, 1936; Weyant and Pareyn, 1975; Lemosquet and Pareyn, 1985). In the Gourara Basin, the Upper Devonian strata are represented within the Kahla clayey Formation (Conrad et al., 1986; Abbache et al., 2019).

In the southern part of the Algerian Sahara (Reggane, Ahnet, and Mouydir basins), the Upper Devonian deposits are represented within a thick (800-1200 m) red and green shales series with the intercalation of silty beds and clays with sandstones lenses on the ridges (Wendt et al., 2006) or archs and paleohighs (Azzel Matti, Arak archs of Perron et al., 2018).

In the Tindouf basin, the Upper Devonian deposits are represented in the Kereb En Naga Formation (Bitam et al., 1996; Legrand, 2000) by the alternation of shales and sandstones 'Griotte' facies of Upper Devonian is also widespread in the Anti-Atlas, and Tafilalt and Maider basins, in Morocco, within platform series (Hollard, 1967, 1974, 1981; Wendt and Belka, 1991; Lubeseder et al., 2010).

This study aims to describe the 'griotte' facies of the Ben-Zireg area, from three sections dated of Frasnian to Famennian, and to characterize the different sedimentary environments with their geodynamic evolution.

2. Geological setting

The Ben-Zireg anticline, the main Paleozoic outcrop of the northwestern Algerian Saharian margin is located 60 km northeastern of the Bechar city (Fig. 1A). It is bordered to the north by the Djebel Antar, to the east by the Djebel Madjouz and to the south by Oued Ben-Zireg and the Zousfana valley (Fig. 1B).

This area belongs to the West African Craton and the Meseta-Atlas area (Michard et al., 1982). The Devonian series of the Ben-Zireg area form an east-west elongated anticline (Fig. 1B, C), surrounded by the Mesozoic sedimentary cover (Houari and Hoepffner, 2003). Three sections were studied in detail on the north and the south flanks of this anticline (Figs 1C, 2).

The Upper Devonian 'griotte' facies is represented by a series of about 100 m thick, forming successive ledges developed between the dolomitic limestones of the Middle Devonian and the black shales of the Lower Visian.

3. Material and methods

Three sections: BZI, BZII and BZIII, distant more than one kilometer each other have been sampled bed-by bed (every 0.5 m) in the 'Griotte' limestone of the Ben-Zireg Formation. Their geographic coordinates are : 31°55'57.25"N, 1°47'11.42"W section BZI; , 31°55'11.74"N, 1°48'09.71"W section BZII and 31°54'40.27"N, 1°47'58.64"W section BZIII. A macro-facies analysis based on field observations (thickness and geometry of the beds, lithology, texture, skeletal and non skeletal components and sedimentary structures), was complemented with a micro-facies analysis of 270 thin sections based on the actualized carbonate facies description as proposed by Flügel (2010).

4. Stratigraphy

4.1. Lithostratigraphic subdivisions of the Ben-Zireg Formation

Based on the lithofacies succession and features, three members (lower, median, and upper) were characterized in the Ben-Zireg Formation (Figs 2, 3A).

The **lower member** (41.50 m) dominated by griotte limestone, consists of decimetric to metric (0.30 to 2.50 m), reddish to greenish, limestone beds intercalated by centimetric to decimetric greenish shales (Fig. 3B, C). The limestone beds are packed in thickening upward cycles capped by ferruginous and bioturbated surfaces. Their microfacies consist mostly of nodular bioclastic mudstones to wackestones containing pelagic (tentaculitids and ostracods) and benthic (echinoderms plates, debris of orthocone nautiloids, trilobites, thin shelled bivalves and crinoidic ossicles) bioclasts. The shale levels contain easily detachable limestone nodules separated by centimetric red clayey-limestone matrix with pyritised brachiopods.

The **median member** (49 m) dominated by clayey-limestone griotte, corresponds to a regular alternation of clayey and 'griotte' limestones packages of mainly decimetric (0.4 to 1.2 m) reddish limestone beds alternating with shales and containing nodular limestones (Fig. 3B, D). The limestone beds are bioturbated and contain flattened limestone nodules; giving the bed regular surfaces with puzzles structures. The fauna is dominated by pelagic (ammonoids and orthocone nautiloids) and benthic (crinoids) groups. The microfacies is mostly constituted of mudstone, more rarely wackestone to packstone with bioclasts of ostracods, bivalves and ammonoids.

The **upper member** (7,50 m) dominated by shales with intercalations of griotte limestone. It corresponds to reddish and foliated shales containing thin 'griotte' limestone beds (Fig. 3E). This unit is characterized by the presence of abundant interstratified nodular limestones (Fig. 3F) highly bioturbated, and intercalated within centimetric limestone beds (0.1 to 0.15 m). They are rich in ammonoids (some specimens are strongly deformed) and also contain some orthocone nautiloids, crinoids and internal molds of gastropods and brachiopods.

4.2. Ammonoid biozones of the Ben-Zireg Formation

The biostratigraphic subdivision of the Upper Devonian strata of the Ben-Zireg Formation has only been roughly investigated on the ammonoid groups (goniatitida and clymeniida) (Menchikoff, 1936; Pareyn, 1961; Massa et al., 1965) and more recently through the study of conodonts only around the Frasnian/Famennian boundary interval (Mahboubi et al., 2015). Based on our newly collected ammonoid material (Abbache, 2019), the taxonomic list established and the biostratigraphic subdivision of the Upper Devonian strata of the Ben-Zireg Formation are currently being revised. Only a biostratigraphic synthesis is reported here. Ammonoid assemblages of the studied area are comparable to those described in the Anti-Atlas of Morocco (e.g., Becker et al., 2002).

Ammonoid assemblages from the Lower Member of the studied formation are characteristic of the *Cheiloceras* Zone (UD II) of the Early Famennian with species belonging to the genera *Cheiloceras* and *Linguatormoceras*. The Upper Member contains characteristic species of the

Gonioclymenia (UD V) and *Kalloclymenia* zones (UD VI) of the Late Famennian, with species belonging to the genera *Kosmoclymenia*, *Cymaclymenia*, *Mimimitoceras*, *Linguaclymenia*, *Prionoceras*, *Cyrtoclymenia* and *Gonioclymenia* (Figs 2, 6). The thicknesses of the identified ammonoid biozones are represented in the most complete section BZI by 40 m zone UD II, 16 m zones UD (III, IV, and V) and 24.5 m zone UDVI. These variations in thickness well expressed in the Saoura region (Abbache et al., 2019; Allaire et al., 2020) show extreme condensation in zones UD III to UD V III to V compared to zones II and VI.

4.3. Main identified facies types of the Ben-Zireg Formation

The main bioclasts used for the characterization of the facies types are: ostracods, tentaculitids, ammonoids, thin shelled bivalves and crinoids with lower proportions of gastropods, trilobites and brachiopods. Based on that, six types of facies (FT-1 to FT-6) have been distinguished within the Upper Devonian 'Griotte' limestone of the Ben-Zireg Formation which are:

Clays with limestone nodules (FT-1). It consists of reddish/greenish clay composed of: (i) laminated shales occasionally containing limestone nodules (Fig. 3E), and/or (ii) slightly silty clays with limestone nodules dispersed or interstratified (Fig. 3F). This facies is characterized by abundant and well-preserved ammonoid shells associated with trilobites, solitary corals, gastropods, brachiopods and rare millimetric bioclasts of crinoids and thin shelled bivalves.

Tentaculitid limestones (FT-2). It forms centimetric to decimetric beds (0.05 to 0.25 m) of reddish to greenish limestone nodules with shale intercalations. The nodules are often bordered by a fine film of micritic matrix. This facies is also present in the upper part of some massive cemented beds highly bioturbated. Two microfacies can be distinguished in this type facies: (i) mudstone to wackestone with recrystallized tentaculites, often associated with ostracods, debris of echinoderms, trilobites, brachiopods and ammonoids (Fig. 4A), and (ii) packstone to grainstone (Fig. 4B) rich in tentaculites (65 to 80%) and containing rare debris of trilobites, brachiopods, and ostracods (about 5%). The mudstones textures are dominant with carbonate muds covering up to 80% of the microfacies, but locally becomes a biomicritic wackestone containing crinoids bioclasts and up to 20% of carbonated mud matrix. The tentaculites tests are ferruginized and often concentrated in millimetric lens-shaped laminae. Hydrocarbon (bitumen) impregnations are observed in some thin sections (Fig. 4A, C, E, G; Fig. 7H) and concentrated along pressure dissolution (stylolites) surfaces implying fluid transports.

Ostracod limestones (FT-3). It is characterized by the abundance of ostracods, and includes two microfacies textures: (i) mudstone to wackestone ostracod texture (Fig. 4C) forming centimetric to decimetric reddish to greenish shaly limestone beds with bioturbated nodules, containing ostracods of the super family Entomozoidea, characterized by ornamented (complete or isolated) valves and occasionally, ammonoids, bivalves and brachiopods debris. Sometimes occur in micritic matrix some rhombohedral diagenetic dolomite crystals and scattered silt-sized grains; (ii) packstone ostracod texture (Fig. 4D) which occurs in cemented and reddish nodular limestone beds of decimetric thickness (0.20 to 0.40 m), rich in ostracods (Entomozoidea) with usually disconnected valves and rare radiolarian tests.

Limestone with thin shelled bivalves (FT-4). It consists of thin bioturbated reddish nodular limestone beds centimetric beds (0.10 to 0.15 m) intercalated within the Lower and Middle members. The microtexture is wackestone to packstone rich in thin-shelled bivalves, associated with sporadic ostracods. The thin shelled bivalves are elongated, unsorted, imbricated and often parallel to the stratification, and wrapping sparitic elements. They form a tissue supported by bioclasts and the micrite seems to be preserved during post mortem infilling between the bioclasts.

Bioclastic limestones (FT-5). The microfacies are of micritic textures with: (i) mudstone (Fig. 4F) containing echinoderm plates and ostracod valves and is characteristic of thin centimetric to decimetric beds (0.05 to 0.20 m) of the cemented reddish limestone beds. This texture (locally wackestone) is mainly composed of ostracods of thin and/or thick tests, as well as some ossicle crinoids often rounded and abraded. Some thin sections of this facies may also contain rare brachiopod, gastropod and bivalve tests and some detrital quartz grains dispersed in the micritic matrix; or (ii) wackestones to packstones containing cephalopod bioclasts (Fig. 4G). This facies is well represented in centimetric to decimetric reddish to green nodular limestone layers (0.10 to 0.40 m) highly bioturbated.

Microbrecciated limestone (FT-6). It is represented by centimetric to decimetric (0.10 to 0.30 m) reddish to greenish and highly bioturbated limestone levels (Figs. 3D, F; 7A, B). The microfacies correspond to mudstone/wackestone with a hematized micrite framing subangular lithoclasts of several millimeters (Fig. 4H). This facies also represented by microbrecciated or gravelly bioturbated limestone levels of some centimetric in thickness (0.10 to 0.30 m). It is a monogenic calcarenite facies with ostracod and bivalve bioclasts and it corresponds to intraformational micro-breccias, fractured *in situ* and without any graded.

The distinction between the automicrite and the allomicrite requires the use of fluorescence techniques or observations with Scanning Electron Microscopy (SEM), but sometimes it is possible to distinguish them based on some observations: (i) the automicrite is a formation *in situ* of fine-grained carbonate particles such as authigenic calcite triggered by a physicochemical, microbial, photosynthetic and biochemical process, (ii) the allomicrite is also called orthomicrite or allochthonous micrite (Flügel, 2010). The microfacies show grain borders (bioclasts, pellets) in contact with a matrix (cement) showing alternations of black micrite and micrite rich in fine bioclastic debris corresponding to an automicrite (Fig. 4C, E). Another type of matrix would derive from the fracturing and destruction of various carbonate grains mixed with fine-grained materials corresponding to an allomicrite (Figs. 4A, B, D; 7D, G, H).

5. Paleoenvironment and deposition conditions of the griotte facies

The 'griottes' facies also called cephalopod limestones (Flügel, 2010) are dominated by micrite often of wackestone textures and containing pelagic fauna (goniatites, orthoceratid, thin shelled bivalves, ostracods) associated with rare benthic fauna (trilobites, echinoderm plates, crinoidic ossicles). This pelagic carbonates was attributed to five major lithofacies categories (Tucker, 1990). The Ben-Zireg 'griotte' limestones correspond to type "C" of Tucker (1990) as thick pelagic limestone on subsided platform. The clay content variations gives large range of bench textural morphology, varying from pure limestone to shaly limestone or nodular limestone and shale with calcareous nodules from early diagenetic origin (Flügel, 2010) induced by biological and physiological actions.

The six facies (Fig. 5) identified from 'griotte' limestone of the Ben-Zireg Formation are dominated by the micrite in pelagic environment (mudstones to wackestones) and suggest a quiet open marine environment where alternate decantation (FT-1) and episodic perturbation by bottom current as tempestites echoes or internalites *sensu* Pomar et al., (2012) and Ouali Mehadji and Bouterfa (2015).

The thin layers with nodules (FT-1) associated with benthic and abundant pelagic fauna, intercalated in clays, indicate open marine conditions and suggest sedimentation in rather deep settings (Böhm et al., 1999). The clays can be produced by decantation or by terrigenous influx.

The tentaculitids (FT-2) are regarded as benthic organisms of deep water by some authors (Berger, 1974; Bouyx et al., 1992) but usually as pelagic organisms inhabiting offshore zone (Flügel, 1982; Kaufmann, 1996, Bourrouilh et al., 1998). The ostracod limestones (FT-3) with

thin-shelled Entomozoidea suggests a relatively deep environment poorly oxygenated (Casier, 2004) and possibly related to fluid seepage (Flügel, 2010) as they are associated to nodular facies, hydrocarbon inclusions and low diversity and high frequency faunas. The fine textured limestones with echinoderm plates and ostracod bioclasts (FT-5) suggest an open marine environment. The echinoderm plates are slightly eroded and probably of floating elements. The microbreccial mudstone (FT-6) seems to correspond to internalite *sensu* Pomar et al., (2012) but can be resulted by reworked/eroded sediment as distal storms, or to local sedimentation influenced by repetitive processes of perforations (bioerosion) after lithification without modification of water energy.

The micrite is the dominant compound and automicrite is present mostly in the microfacies FT-4 while the presence of the fauna as molluscs (ammonoids, orthocetamid, thin shelled bivalves) tentaculitids and ostracods should participate directly on the floor by degradation of their biomineralized shells or partly provided as allochthonous lime by bottom currents. Then, the carbonate factory of the Ben-Zireg supply is biologically controlled carbonates type positioned on southwestern area of Ben-Zireg combined to influenced carbonate type *sensu* Pomar (2020).

These six microfacies are characteristics of a pelagic mud dominated distal ramp (*sensu* Ahr, 1973; Read, 1985; Burchette and Wright, 1992), where the sediments are deposited below the storm wave base and the photic zone. The microbreccia levels may correspond to the echoes of distal storms deposits or caused by perturbation induced by the breaking of the internal waves when they intersected the sea floor. All this facies corresponds to Standard Microfacies Types SMF3 and SMF8 of Flügel (2010) of deeper outer ramp zones.

The reddish mudstones of the 'griotte' facies seem to indicate phases of poorly oxygenated seafloor (dysoxic to suboxic). Such environments are well-known in the European Paleozoic (Mamet and Boulvain, 1988, 1990; Mamet et al., 1997) and correspond to a sedimentation realized under a hundred meters of water.

The absence of sedimentary structures of high energy environment suggest that the whole microfacies (FT-1 to FT-6) dominated by the micrite with bioclasts are settled in low energy environment to quiet water sedimentation (claystones).

6. Discussion and geodynamic position of the nodular 'griottes' facies

The carbonate factory concept (Matti and McKee, 1976; Wright and Burgess, 2005; Tucker and Wright, 1990; Pomar, 2020) combines the zone of production, the association of benthic producing organisms and the specificity of the time window.

The structuring of the north and northwestern gondwanian carbonate platform (South Morocco and Algerian Sahara) as ridges, basins and slopes (Wendt and Aigner, 1985; Wendt, 1988; Lubeseder et al., 2010) is the expression of the structure of the Precambrian basement and the replay of fractures (Precambrian heritage) during the subsequent tectonic phases (Perron et al., 2018). The Ben-Zireg paleogeographic position as an intermediate zone between the Saoura valley in the southeast and the turbidites zones in the north (Algerian High plains and Moroccan Meseta) with the facies basin and abyssal plains allows to understand and visualize the carbonate production area and the dynamics of their distribution.

The Frasnian-Famennian extensive movements (Fabre, 1976, 2005; Ouali Mehadji et al., 2012; Perron et al., 2018) were slow, extended in time (Lubeseder et al., 2010).

The carbonate factory positioned in mid ramp exports the carbonate lime by reworking sediment and exportation by the bottom currents (Pomar, 2020). Below the storm wave base, this exportation is mediated by the gravity currents and the internal waves. The median ramp facies known at this time, corresponds to the platforms in the Maider-Tafilalt zones.

The reddish color ('wine' color) of the 'Griotte' facies of the Ben-Zireg Formation is indicative of the high level of ferric iron caused by hematite imprints (Auboin, 1964) (Fig.

7A) and may reflect the important effect of the oxidation-reduction processes mediated by ferro-oxidizing bacteria, inducing the red pigmentation (Ghiorse, 1984). Two distinct origins have been proposed to explain this red pigmentation: (i) a detrital origin of hematite (Reijers, 1984), or (ii) a microbial origin (Monty et al., 1982; Boulvain, 2001; Boulvain and Coen-Aubert, 1989; Pr at et al., 1998 a, b; Bourque and Boulvain, 1993). These bacteria confirm the biotic mode of automicrite production as influenced type mostly for the nodular facies in shales by degradation of the organic matter as shown by several works (Gluyas, 1984; Beveridge and Doyle, 1989; Mann, 1992; Emerson and Revsbech, 1994; Munneck and Samtleben, 1996).

In this 'griotte' facies, the nodular structures are mainly represented in rhythmic (alternating clayed limestone) (Fig. 7A). These rhythmicity can result from diagenetic alteration (Einsele, 1982) or from sedimentary deposits (Weedon and Jenkyns, 1999). In addition to the both diagenetic and sedimentary origins, a micro-tectonic (micro-shearing) origin has been proposed by Fl gel (2010).

The nodular structures present in the 'griotte' facies of the Ben-Zireg Formation are flattened and compressed due to compaction-dissolution events (Fig. 7B) and show at a microscopic scale: (i) frank contacts with a clear boundary between the matrix and the various figured elements (Fig. 7C); (ii) filamentous contacts indicated by the flow of the matrix and the interlocking of the still plastic nodules during the compaction stage (Fig. 7D); and (iii) progressive contacts that is more represented during the moment of the bioturbation of the sediments; These contact characterized the nodules packed in mud-clay during the lithification (Fig. 7E).

The bioturbation in the 'griotte' facies is attested by the abundance of macrofauna and microfauna as tentaculitids and ostracods (Fig. 7D, E, G, H) and sometimes recrystallized and surrounded by thin hematitized dandruff (Fig. 7G, H). This bioturbation probably due to the activities of endobiont organisms is affecting the sedimentary particles (Kristensen et al., 2012). It includes a distribution and a reshuffle generating significant changes in the physical, chemical and even biological properties during the sedimentation.

The majority of the limestone levels shows bioturbation surfaces (puzzle structure), corresponding to either slowdowns as indicated by the hard-grounds. These structures resulting from the organic activity show a thin irregular and multi-millimetric stratiform crust in a reddish micritic matrix.

The carbonate factory ends in the south of the Maider Platform during the Late Devonian after exposure of the platform in Morocco (Wendt, 1988) and Algeria (Pareyn, 1961).

Because of its location on a fore-deep mobile area (Kazi-Tani et al., 1991), between the High plains-Meseta area and the Anti-Atlas/Ougarta zone (Michard et al., 2010), the Ben-Zireg basin is a key region to understand the paleogeography of the northwestern Sahara during the Paleozoic. This area is marked by extensive tectonic that occurred slowly during the Upper Devonian who configured it in basin and ridges (Dreesen, 1989; Saunders and Ramsbottom, 1986; Wendt and Aigner, 1982; Wendt et al., 2006; Fabre, 1976, 2005; 2010; Perron et al., 2018).

The development of the nodular 'griotte' facies is also described in several areas in North Africa, such as the northwest part of the Anti-Atlas of Morocco where it shows condensed facies deposited on ridges and marls-limestones alternation at the basin with rapid lateral changes (Wendt, 1988; Lubeseder et al., 2010).

At 250 km to the south, in the Ougarta (Saoura), the Upper Devonian deposits are represented by a thick series (700 m) with a detritic dominance, episodically intercalated by 'griotte' facies (less than 20% of the total thickness) well developed in the Frasnian (Ib) and in the Famennian (zones III, IV) deepening meso-sequence that evolved in from median ramp to

distal and finally slope position. Toward the south (Reggane, Ahnet and Mouydir areas), this 'griotte' facies **lack** and replaced by siliciclastic deposits.

The roughly oriented east-west linear area of the Moroccan Anti-Atlas via Ben-Zireg and finally to the Ougarta chains, marks the development of the nodular "griotte" facies also known as the limestone cephalopod facies. It draws a gateway towards the deep turbiditic plains of the Meseta and the **High Plains**. This nodular **facies** area is wedged between the West African Craton in the south and the northwest edge of the western arm of the Tergui Precambrian basement, **in geodynamic flexural structure**. It would express a development of a continental slope as zone of flexure towards the north Gondwanian deep marine areas.

As in the griottes of the Montagne Noire (Pr at et al., 1999), the fine micritic nature of the sediments (mudstone and wackestone) in association with **shales** in the Devonian series of the Ben-Zireg area, suggests an autochthonous sedimentation, relatively calm and interrupted locally by inputs (packstone with **micro-breccia**) representing tempestite levels. This trend may highlight a distal gradient in the sense of Aigner (1985). The high abundance of **hard grounds** accompanied by thin ferruginous crusts in the Devonian series of the study area indicates a pelagic environment as in the Moroccan area (Becker et al., 1989). We must insist on the importance of red mudstones in the series that represent relatively deep environments poorly oxygenated, located near the baseline of the storm action zone. Such environments are well known in the Paleozoic of Europe (Mamet and Boulvain, 1988, 1991; Mamet et al., 1997).

7. Conclusion

The "griotte" facies of the Upper Devonian comparable to the ammonitico-rosso (**Jurassic**) facies is characterized by its reddish / greenish color and its condensed sequences. It is part of the north of Gondwana (Anti-Atlas of Morocco, Ben-Zireg and Ougarta in Algeria) and the south of Eurasia (Montagne Noire in France, the Pyrenees, Germany and the Czech Republic).

The "griotte" facies of the Upper Devonian so-called cephalopod limestones of the Ben-Zireg corresponds to rhythmic alternations of nodular limestones and clays with an abundance of nodular structures, hard-grounds and the richness in ammonoid faunas (goniatitida and clymeniida).

This facies is divided into three members: (i) the Lower member ("griotte" limestone) from the Frasnian to the lower Famennian (zone II), (ii) the Median member (clay-limestone "griottes") from the lower to the upper Famennian (top of zone II - bottom of zone VI) and (iii) the Upper member ("shales with intercalations of 'griotte' limestone) from the upper Famennian (top of zone VI). The dating of the ammonoids is corroborated by a new ammonoid material. Indeed the genera *Cheiloceras* associated with *Linguatornoceras*, *Gonioclymenia* and *Kalloclymenia* confirm respectively the Famennian Zones (UD II), (UD V) (UD VI).

The **microfacies** analysis of thin sections showed limestone nodule clays and fine-grained carbonates dominated by textures (mudstone, wackestone) and debris of: (i) pelagic fauna (cephalopods, tentaculitids) and (ii) benthic forms (ostracods, thin-shelled bivalves, trilobites, gastropods and crinoids).

All this facies are sedimented in the distal ramp submitted to decantation process (FT-1) alternate by benthic debris fauna and fall-out of the pelagic and nectonic organisms arrival. The absence of sedimentary structures and facies of high energy suggests a quiet environment represented by an oxygenated ramp but swept by bottom currents from storm echoes or the effects of internal wave. This finding is attested by the dominance of fine micritic textures, tentaculites and ostracods fine tests as well as by the abundance of pelagic faunas of ammonoids.

The effect of early diagenetic are numerous and produce the in-situ automicrite, the degradation of organic matter essential for the ferro-oxidizing bacteria pigmentation, bioturbation (by feeders fauna) and **nodularization**. The carbonate factory of the Ben-Zireg supply is of biologically controlled carbonates type positioned on southwestern (Platforms of Tafilalt and Maider) of Ben-Zireg combined to influenced carbonate type *sensu Pomar (2020)*.

The **paleogeographic** position of Ben-Zireg appears as an intermediate milestone between the Ougarta in the southeastern, the Anti-Atlas in the southwestern and finally the deep turbidite zones (Meseta and High plains) in the north. Does it herald the beginning of the flexion of the Gondwanian slope.

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Figures captions

Fig. 1. Geographic and geological maps of the Ben-Zireg area (Bechar Basin, western Algeria). A) Distribution of the Devonian outcrops in the Sahara (Fabre, 2005, Modified). B) Geological sketch of the Ben-Zireg anticline (Pareyn, 1961, Modified). C) Satellite view (after Google Earth) with location of the three studied sections.

Fig. 2. Lithostratigraphic columns of the Upper Devonian 'griotte' limestone of the Ben-Zireg Formation (Ben-Zireg area). A) The three studied sections. B) Legend and spatial distribution of the studied sections.

Fig. 3. Field views of the different lithological units of the Upper Devonian 'griotte' limestone of the Ben-Zireg Formation (Ben-Zireg area). A) Panoramic view of the Devonian series corresponding to the northern slope of the Ben-Zireg anticline: 1) Givetian dolomitic limestones of the "Carbonate of three palm Formation", 2) 'griotte' limestone, 3) 'griotte' clayey-limestone, 4) Shales with intercalations of 'griotte' limestone, 5) Viséan shales with olistostroms. B) Photographic view showing the upper part of the 'griotte' limestone unit and the lower part of the 'griotte' clayey-limestone unit. C) The massive beds of the 'griotte' limestone unit. D) The regular alternation of the 'griotte' clayey-limestone (middle part of the unit). E) shales intercalated in the 'griotte' clayey-limestone unit. F) Shales with nodules (top of the series).

Fig. 4. Microfacies, in thin sections, of the Upper Devonian 'griotte' limestone of the Ben-Zireg Formation. m: matrix, n: nodules. A) Mudstone/wackestone with tentaculitids (t) and conodonts (c) from the 'griotte' limestone (lower unit of the Ben-Zireg Formation) (FT-2; sample Oz-14, section 'III'). B) Packstone/grainstone with tentaculitids (t), conodonts (c), and bivalves (b) from the 'griotte' limestone (FT-2; sample Oz-15, section 'III'). C) Mudstone/wackestone with ostracods (o) from the 'griotte' clayey-limestone (middle unit of the Ben-Zireg Formation) (FT-3; sample Ob-15, section 'III'). D) Packstone with ostracods (o) from the 'griotte' clayey-limestone (FT-3; sample Be-34, section 'II'). E) Wackestone/packstone with filaments (f) from the 'griotte' clayey-limestone (FT-4; sample Be-13, section 'II'). F) Mudstone with echinoderm plates (ec) and ostracods (o) from the 'griotte' clayey-limestone (FT-5; sample Be-8, section 'II'). G) Cephalopod wackestone/packstone (g) with gastropods (gs), ostracods (o), bivalves (b), and echinoderm plates (ec) from the shales with intercalations of 'griotte' limestone (upper unit of the Ben-Zireg Formation) (FT-5; sample Z-36, section 'I'). H) Micro-breccia mudstone with detrital quartz grains from the 'griotte' clayey-limestone (FT-6; sample Ob-16, section 'III').

Fig. 5. Paleo-environmental reconstruction of the Upper Devonian 'griotte' limestone of the Ben-Zireg Formation.

Fig. 6. Ammonoids from the Upper Devonian 'griotte' limestone of the Ben-Zireg Formation (scale bars: 1cm)

- 1- *Cheiloceras* sp.; 1a-b. Lateral view, 1c. Frontal view; specimen Be2.5, (section BZII).
- 2- *Cheiloceras crassum* Wendekind, 1918; 2a-b. Lateral view, 2c. frontal view; specimen Oz1'.1, (section III).
- 3- *Cymaclymenia* sp.; 3a-b. Lateral view, 3c. Frontal view; specimen Z35.12, (section BZI).
- 4- *Cymaclymenia* sp.; 4a-b. Lateral view, 4c. Frontal view; specimen Z37.31, (section BZI).
- 5- *Kosmoclymenia* sp.; 5a-b. Lateral view, 5c. Frontal view; specimen Z37.5, (section BZI).
- 6- *Kosmoclymenia* sp.; 6a-b. Lateral view, 6c. Frontal view; specimen Z37.10, (section BEI)

- 7- *Cyrtoclymenia* sp.; 7a-b. Lateral view, 7c. Frontal view; specimen Z37.24, (section BZI).
- 8- *Gonioclymenia* sp.; 8a-b. Lateral view, 8c. Frontal view; specimen Z37.8, (section BZI).
- 9- *Linguaclymenia similis* Münster, 1832; 9a. Lateral view, 9b. Frontal view; specimen Z37.6, (section BZI).
- 10- *Linguatornoceras* sp.; 10a. Lateral view, 10b. Frontal view; specimen Be2.2, (section BZII)
- 11- *Mimimitoceras* sp.; 11a. Lateral view, 11b. Frontal view; specimen Z37.33, (section BZI).

Fig. 7. A) Panoramic view showing the red color (hematite imprint) and the rhythmic alternation of the 'griotte' clayey limestone. B) Nodular structure with flattened nodules formed by compaction-dissolution processes. C) Frank contacts between the matrix (m) and the nodules (n) in a microfacies showing a mudstone texture, 'griotte' limestone unit. Nodules surrounded by thin hematitized dandruff are visible (white arrow). D) Microfacies characterized by a wackestone texture, 'griotte' limestone unit. Filamentous contacts can be observed between the matrix (m) and the nodules (n). These contacts indicate the flow of ostracodes (os) and tentaculites (te) in a fluid matrix (m) and the interlocking of the nodules still plastic during the compaction stage. E) Microfacies corresponding to a bioclastic mudstone, showing progressive and fuzzy contacts between the nodules (n) and the matrix (m) with recrystallized ostracodes (os) (white arrow). These contacts reflect the bioturbation process (nodules packed in a clay mud during the lithification). F) Microfacies showing a mudstone texture with particular imprints generated by microbial activity (black spots) indicating the important role of microorganisms during the early diagenesis. Thin hematitized dandruff (white arrow) is common on the borders of the nodules. G) Bioclastic wackestone with gastropods (ga), ostracodes (os) and filaments (fi) in a hematite matrix (m). Nodules (n) affected by microbial activity. Some bioclast sections are recrystallized and hematitized (yellow arrows). H) Bioclastic microfacies with goniatites (go) and ostracodes (os), wackestone texture, ferruginous fluidal matrix (m). The goniatite section is surrounded by a thin ferruginous millimetric film (white arrow).